HORIZON 2020

THEME SC5-2017

(Grant Agreement 776613)

European Climate Prediction system (EUCP)

Deliverable D4.1 + MS15

Review of user needs and list of impact indicators

Deliverable Title	*Review of user needs*	
Brief Description	*This task gathers and reviews stakeholder analysis, interviews and surveys conducted within previous and ongoing projects to list and sort user needs for the EUCP service.* *It also produces a list of most relevant indicators ready for further analysis in case studies and end users in WP6.*	
WP number	4	
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Creation Date		*30/10/2018*
Version Number		*4.0*
Version Date		*29/11/2018*
Deliverable Due Date		*30/11/2018*
Actual Delivery Date		*19/11/2018 (v3) / 30/11/2018 (v4)*
Nature of the Deliverable		*R – Report*
Dissemination Level/ Audience		*PU – Public*

Version	**Date**	**Modified by**	**Comments**
1.0	30.10.2018	S. Bathiany (HZG)	First draft
2.0	09.11.2018	S. Bathiany (HZG)	Modified based on comments by Dragana Bojovic (BSC) and Dominic Matte (UCPH)
3.0	19.11.2018	S. Bathiany (HZG)	Technical corrections
4.0	30.11.2018	S. Bathiany (HZG)	Modified based on additional comments by anonymous internal reviewers and Francisco Doblas-Reyes (BSC)
5.0	20.12.2018	S. Bathiany (HZG)	Modified based on additional comments by Jason Lowe (UKMO) and Francisco Doblas-Reyes (BSC)

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1 Executive summary

This report reviews users' needs by gathering and comparing stakeholder analyses, interviews and surveys conducted within previous projects (e.g. from C3S and H2020) in order to guide the setup of the multi-user forum of the EUCP service. In comparison to previous projects, the time scale in mind is broad (1-40 years), hence climate information may come from a seamless combination of initialised predictions as well as projections driven by concentration and emission pathways. In addition, a list of climate change indicators has been compiled as a basis to identify potential prototype products for applications on such timescales. The report is complemented by conclusions and suggestions for involving users in EUCP.

2 Project objectives

These deliverables have contributed to the following EUCP objectives (Description of Action, Section 1.1):

No.	Objective	Yes	No
1	Develop an ensembles climate prediction system based on high-resolution climate models for the European region for the near-term (~1-40 years)		x
2	Use the climate prediction system to produce consistent, authoritative and actionable climate information	(x)	
3	Demonstrate the value of this climate prediction system through high impact extreme weather events in the near past and near future	(x)	
4	Develop, and publish, methodologies, good practice and guidance for producing and using EUCP's authoritative climate predictions for 1-40 year timescales	x	

3 Detailed report

3.1 Objectives and approach of this report

Objectives of this report:

- Gather and review stakeholder analyses, interviews and surveys conducted within C3S projects and ongoing H2020 projects (EUCP Task T4.1)

- Compile a list of impact indicators most relevant for end users (milestone MS15)
- List and prioritise user needs for the EUCP service and make recommendations for upcoming user-related activities within EUCP's multi-user forum (MUF) as described in D6.15

Approach

This report reviews previous experiences with user engagement, focusing on the content and conditions of interactions between scientists and users. In contrast to many previous projects, there is no focus on one specific time scale because the climate information provided by EUCP will comprise initialised predictions as well as projections driven by boundary conditions (forcing scenarios). The report intents to support the identification and involvement of stakeholders for EUCP's multi-user forum. A focus is therefore put on aspects pointing to crucial challenges and opportunities for the user-involvement in EUCP, considering the set-up of the multi-user forum and the research plans within all work packages.

3.2 Selection criteria for reviewed literature

This report reviews selected project reports from previous projects such as CLIM4ENERGY, CLIPC, DECM, EU-MACS/MARCO, EUPORIAS, ReKliES-DE, SECTEUR, and peer-reviewed articles (see References). Based on the objectives above, the following criteria for selecting this literature were applied:

- Selected projects from recent years that had a focus on user involvement and direct feedback by users (for example via surveys and interviews), including end users outside of the academic realm.
- User types are relevant for EUCP, i.e. involving groups of political decision-makers and practitioners as these groups are targeted by the multi-user forum.
- The regional focus is on Europe.
- Projects addressed time scales within the EUCP prediction horizon of 1-40 years (e.g. decadal climate predictions and projections).

3.3 User requirements

Regarding user requirements, a few themes were commonly recognized in the reviewed literature and resources: the classification of users, their data requirements, desired resolution, uncertainty and prediction skill, timescales, and required climate variables and indicators. These themes will be discussed in the following subsections, supplemented with recommendations for the seamless-prediction context of EUCP.

3.3.1 Definition of users and composition of user groups for EUCP

A user of climate services is generally defined as "an individual or organization with responsibilities for decisions and policies in climate-sensitive settings, to whom some form of climate information is delivered." (Cortekar et al., 2017). Users of climate information are typically classified into several groups ranging from climate researchers, climate impact researchers and climate service providers, to so-called end users who need a climate service as one requirement for their own applications (for example see CLIPC, 2016). The Data Evaluation for Climate Models (DECM) project also introduced a categorisation in terms of data usage (data users, product users, non-users).

Some recent projects conducted extended surveys among users with more than 400 participants each (DECM: 481 participants, SECTEUR: 438 participants, EUPORIAS: 489 participants, and 80 participants in additional interviews). Most users that took part in these surveys work in the academic realm, while end users were less represented. It is not always clear to which extent this outcome is representative because the process of finding participants is biased by the typical academic communication channels scientists used for the surveys. It is clear however that end users are the most heterogeneous group in terms of their background knowledge, their expectations and their applications of climate-related information (FMI, 2017b). For example, their needs differ between the type of organisation (private or publicly financed), the societal sector, the region and time scales of operation, and the role of individuals in an organisation. Moreover, users have different background knowledge about climate change-related information, which affects the support they require, and the extent to which they perceive climate change to be relevant to their activities. It is therefore challenging to obtain a representative overview of user needs in general.

Soares et al. (2018) recently interviewed users representing a number of sectors including agriculture, forestry, energy, water, tourism, insurance, health, emergency services and transport sectors. Users from the sectors of forestry, agriculture, energy, water, and transport explicitly expressed their interest in predictions on multi-annual time scales. The health and tourism sector can also be expected to be affected by the changing climate, but did not express their needs for new climate information, arguably due to the small size and hence limited resources of the organisations involved in the surveys (Soares et al., 2018).

Recommendation: Research within EUCP focuses on methods for merging timescales (seamless prediction, overcome initialisation shocks, ...), bridging spatial scales (regional downscaling), and evaluating model predictions (Hewitt and Lowe, 2018). It is recommended that the final list of users to be contacted draws from the above sectors. The associated Multi-User Forum (MUF) is currently intended to consist of two groups, political decision makers (for example, representatives from the European Commission, OECD, the European Investment Bank, the UK department of Business, and the World Meteorological Organisation), and practitioners (for example a company in the wind energy sector, a consultancy firm for hydrological risk and disaster management, or a wine producer). Milestone 25 of EUCP currently lists potential users (preliminary and internal document), the process to involve users is defined by Mysiak (2018).

As little climate-impact related research is involved in EUCP research (apart from collaborations with end users in WP4), it may be beneficial to involve different types of users for the multi-user forum (MUF), covering the whole product chain from fundamental research to impact research and applications on a local scale, and involve different levels of political decision making.

3.3.2 Process and conditions of user involvement

Previous projects have involved users in different ways, and addressed different types of users. The newer the projects, the more they tended to establish contact with end users (FMI, 2016). Ways of communication and collaboration included workshops, education sessions, leaflets, interviews and the co-development of prototype climate services.

Because every case of user involvement differs, the Copernicus Climate Change Service (C3S) identified the need to establish a "community of practices" in the co-production of climate knowledge because "none of the projects have systematically evaluated the effectiveness of user engagement methods or the actual usefulness of the provided data in portals, neither during nor after their implementation. So identifying the best way to engage with users and implement their requirements in a satisfactory manner that is still under development and should be intensively researched." (FMI, 2017a)

Recommendation: It can be argued that EUCP is approaching the user involvement in two different ways: A bottom-up approach, and a top-down approach. The bottom-up approach refers to collaborations with end users in order to directly satisfy their specific needs and (co-)develop products that are practically relevant for their operational activities. Such an approach is represented by WP4 activities T2.4a, T2.4b, and T2.4d (though the initiation of the project still comes from the academic realm). The top-down approach is represented by the envisioned multi-user forum (MUF) of WP6 (Mysiak, 2018). In order to learn from EUCP activities for future projects, it could be beneficial to document and compare the experiences in the different activities within WP4 and the MUF, but also between the two approaches.

The fragmentation of research, of users and their diverse applications, and of the interactions between them does not allow a general statement about the ideal method to engage users (FMI, 2017a). However, several general preconditions that facilitate a sustainable user-engagement can be identified from all analysed previous projects:

- Trust and confidentiality between scientists and users, but also between different users. This trust requires full transparency about the process and realistic aims of the project, and refers to the personal as well as the institutional level. For example, users have relied on national weather services for their operational activities for a long time, which makes them trustworthy institutions for users regarding climate services for longer-term predictions. Building on existing relationships between data providers and users has been shown to work well (Dessai and Soares, 2015)

  Recommendation: This experience suggests to make use of current partnerships between EUCP scientists, practitioners and political decision-makers when assembling the multi-user forum (milestones MS25 and MS28). Instead of aiming for large meetings with ~30 diverse users from the MUF and EUCP scientists, it is recommended to define smaller teams of users and scientists who focus on their own specific goals (for example developing a prototype climate service, or at least assessing its feasibility), coordinated by WP6.

- Clear and extensive communication. In a transdisciplinary environment, very clear, elaborate and frequent communication is required between the actors. The communication between users and climate change experts should not be a hierarchical one, but rather a horizontal exchange of knowledge and experiences. Therefore, the user should be part of the scientific process and the scientist should also be included in the user’s process. This approach requires time and commitment (Buontempo et al., 2018). Such resources have been identified as an important precondition for a sustainable user engagement, which is often hindered by lack of time and the lack of incentives like reimbursement for the user's efforts.

  Recommendation: Enough time should therefore be attributed to activities of the MUF (depending on the activities planned). Due to the lack of a travel budget for the MUF, the members of the Task Force (WP leads) and WP6 scientists are encouraged to identify opportunities for face-to-face meetings at common events, for example by hosting sessions at popular conferences like ECCA or EGU, and by organising back-to-back events with EUCP's general assemblies. Such events however have the restriction that they usually only attract users from the academic realm (and some political organisations or funding agencies), but not many practitioners. It is therefore advisable to also work in smaller teams on selected issues and use or establish personal contacts to practitioners.

- Comprehensive documentation. The experiences with user engagement should be well-documented and made public. Experience from previous projects are usually not well documented, (as reflected in the aim of this report, i.e. reviewing previous H2020 projects), and projects keep repeating in the view of stakeholders (FMI, 2016), who can become fatigued by scientific projects that do not provide them with sufficient use. Improvements can therefore be made when documenting the experiences from different projects and the actors involved, and passing on this information in a comprehensive way, ideally integrating experiences from different projects. Most importantly, the documentation should not only capture the contents but also the processes of the user involvement, in order to learn from each case, "whether successful or not" (FMI, 2017b).

- Collaboration. It has proven to be most motivating to users when a common goal requires collaboration, in contrast of only transferring general information (either by passing knowledge from scientists to users, or communicating demands from users to scientists).

  The development of so-called prototypes is a very effective way of user involvement, e.g. see reports from MiKlip and EUPORIAS (Buontempo et al., 2018). Prototypes are very specific pieces of climate information with a user-relevant purpose that are identified and created in close collaboration between scientists and users. In contrast to non-prototype services like standardised predictions or information, these services establish a new product. Users can thus have a direct and long-lasting influence on the direction of research, and work toward an achievable and beneficial goal, which enhances and sustains their motivation.

  A challenge in this regard is the large gap between the realms of climate modeling and end users in terms of spatio-temporal scales and prediction uncertainties (including lack of scientific knowledge and lack of prediction skill). Moreover, the diversity of applications makes it challenging to identify a certain aspect of climate predictions that is specific enough for the user's practical application and general enough to be of interest to many other users.

Recommendation: To address these challenges, the upcoming activities involving EUCP's multi-user forum should identify the overlaps between the following questions:

1. What type of knowledge can EUCP provide given the structure and tasks within the project?

2. What goals are scientifically interesting and realistic, e.g. where can we expect prediction skill, or reduce the relevant prediction uncertainties?

3. What applications are interesting for users and what resolution and uncertainties can be tolerated for these applications?

Given the broad scope of EUCP, it will be required to identify specific user-relevant showcases or even prototypes, and define the next steps to develop them. For example, EUCP could contribute by evaluating the skill in predicting certain indices on a local scale, involving guidance by users from the MUF. Potential candidate topics are the yield of wind energy, the damages from storms and their effect on insurance companies, the prediction of fish stocks on decadal scales (involving the Technical University of Denmark), and the risk of extreme rainfall events and floods in Europe (involving several of the envisioned stakeholders from hydrological institutes and companies).

The triangulation outlined above requires the participation of key scientists from several EUCP work packages as well as member of the MUF and its task force, which emphasises the need to host back-to-back sessions with other conferences.

At least in the first project phase, the MUF members will primarily have the role of consultants, guiding EUCP scientists in the selection of the most useful showcases and products. Provided the experiences made in previous projects it may be beneficial to not only formulate realistic and quantifiable goals for project deliverables, but also explore, document and evaluate the applied methods of user involvement, or even let the users evaluate the project - something that has not been done before (FMI, 2017a).

3.3.3 Data requirements

Users generally express interest in data that is free, consistent (i.e. does not differ between sources), easy to find, download and use (including specific subsets of data), includes guidance and long-term support from scientists, is well documented, and includes information about the nature and magnitude of uncertainties (CLIPC, 2016; FMI, 2017b).

Recommendation: Although EUCP is not planning to establish a new data platform, WP1 and WP2 activities to compile information on existing predictions and their uncertainties could be beneficial to users when made public.

A helpful way of communication is to provide climate change related information in the form of storylines and storymaps, including graphical information. One example is information provided in a form of storymaps at the PRIMAVERA User Interface Platform (https://uip.primavera-h2020.eu/storymaps /)

Recommendation: The identification of user-relevant scenarios and events at the WP2 workshop (milestone MS10) can thus help to facilitate the communication with MUF participants and could serve as content for the planned webinars in WP6 (Mysiak, 2018).

3.3.4 Spatial scales

Increasingly users are interested in a more detailed picture of the local climate and its evolution. In order to build trust in climate predictions, they also require the evaluation of these predictions to be performed at the local level, at which the application occurs. While this represents a challenge for the climate modelling community, it also offers the chance to involve specific users in the model evaluation, thus creating benefit in collaborations between scientists and users instead of unidirectional information-flow.

Recommendation: For example, WP3-related activities (demonstration of value of the EUCP system through investigation of events) might consider to check their findings using certain past weather events and the experiences of organisations that felt the impacts of these events.

3.3.5 Uncertainty and prediction skill

In order to build trust in climate predictions, it is very important for users to obtain understandable and comprehensive information about uncertainties. Consequently, DECM identifies the issue of uncertainties and the evaluation of predictions as more important than the need for higher resolution. Since users typically require both, there is a trade-off between quantifying model uncertainties and investing resources into higher resolution.

Recommendation: EUCP is well positioned to address this trade-off, since both aspects are captured in the project (WP2 dealing with uncertainties, and WP3 with high-resolution modelling). It might be worth considering whether they can be combined in a specific way most relevant for users, for example by exploring uncertainties of a high-resolution event as a showcase developed by WP5.

Users have different expectations about how uncertainties should be communicated in terms of quantitative information (yes/no decisions, ensemble of scenarios, probabilistic estimate, probability density functions, ...) and visualisation (maps, graphs, charts, ...) (Dessai and Soares, 2015), hence a variety of approaches may be best suited to cover different needs. In all cases it is essential to make the procedures of quantifying uncertainties very transparent and consistent.

Recommendation: EUCP is therefore best positioned to not only quantify and reduce uncertainties, but explore new and better ways to communicate and illustrate them. Their tasks related to producing pdfs for certain weather events might benefit from feedback by the multi-user forum (MUF), for example within webinars or common meetings like the upcoming session at the European Climate Change Adaptation conference (ECCA).

The definition and evaluation of prediction skill is a crucial element for building trust between scientists and users and illustrating the potential of a European climate prediction system. The term prediction in this context refers to the credibility of projections as well as the actual prediction when initialising simulations based on the current climate state because users will not be very interested in (or educated about) the difference of the two components. Two major obstacles are commonly mentioned that hinder direct applications of climate predictions:

1. Users are operating under a variety of uncertainties, which are not only related to climate change. For example, even if the probability of a certain weather event was known exactly, it can remain uncertain what impacts this weather event would typically cause in practice.

2. Users express that the reliability of multi-annual climate predictions so far is too low to affect their decisions.

It should be noted that decadal predictions have made huge progress in the past 10 years, maturing from proof-of-concept studies to operational products that are now published online, for example by the MetOffice (https://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/long-range/wmolc-adcp) and the MiKlip project (https://www.fona-miklip.de/decadal-forecast/decadal-forecast-for-2018-2027/). It has also become clear that there is a substantial demand for such predictions in many sectors (Alexander et al., 2016; Lamich et al., 2018; Kielmanowicz, 2018). However, despite this scientific success story and the many potential applications of operational decadal predictions, the value of these predictions is not yet convincing for users and often regarded as "unchartered territory" [sic] (Dessai and Soares, 2015). For example, it is yet uncertain what users actually look at the predictions on the two websites mentioned above. In fact, both include disclaimers that labels the predictions as experiental and advise users against using the predictions as a basis for any decisions.

A comprehensive assessment of prediction skill in general remains challenging because the skill depends on many factors like the model, the variable, the region, the season, the lead time, the number of ensemble members used, and the evaluation method (Tiedje et al., 2016; Bojovic, 2018). The evaluation of predictions is particularly difficult on such long timescales (especially regarding rare events) because the short observational records cause a large uncertainty in the true frequency of the predicted event (Corti et al., 2012).

Most studies focus on temperature as the predictive variable, averaged over a certain time (such as a season or longer). For Europe, they found significant skill for lead times of several years (Kim et al., 2012; Corti et al., 2012; Doblas-Reyes et al., 2013). Typically, the effect of the climate forcing (increase in greenhouse gases) contributes most to this skill, whereas the added value of the initialisation is often small, casting some doubt on the benefit of seamless predictions compared to projections in this context.

Decadal forecasts are often conducted with an ensemble of model simulations and the skill is then quantified in a probabilistic sense. It has to be considered in this context that a high forecast reliability does not necessarily imply a high level of certainty on future temperature. A forecast may therefore be seen as reliable (in technical terms) by scientists, but unreliable by users. For example, if the true probability of a positive temperature anomaly during the next 5 years is 50%, and if 50% of the ensemble members of a prediction system show a positive tendency, the forecast is reliable in a statistical sense. While such information is obviously better than having no prediction, it is a different question if users would regard such information as relevant for their planning. For example, some participants of the EUPORIAS interviews, representing different sectors, stated that they only consider predictions as relevant for their actions if the predicted event will actually occur with a probability of at least 70-75% (Dessai and Soares, 2015). It is not clear whether this attitude can be changed by a better communication of scientific results, or only by improved skill.

> **Recommendation:** Considering that internal climate variability can easily counteract the forced component on timescales of several years, it might be worthwile to explore with users for what applications the identified skill is sufficient. It might be a challenge to the user involvement in EUCP that a focus lies on hydrometeorological extreme events, in the sense that precipitation has been found to have relatively small prediction skill compared to user expectations (and compared to temperature-related indices).
>
> A related challenge lies in the communication with users: The evaluation metrics used in research to quantify prediction skill (such as anomaly correlation coefficient or Brier skill score) are not necessarily the best properties for informing users without a climate research related background. It should therefore be attempted (e.g. in WP2 of EUCP) to translate such probabilistic measures into information that is easy to understand.

Other variables than temperature have usually been found to show such low levels of skill that their relevance for users has not been fully established. Relatively few studies assessed the skill in a way that is relevant for users, like focusing on climate indicators or specific extreme events (for an example, see Hanlon et al., 2013). As pointed out in EUCP report D6.4 (Bojovic, 2018), sectors that are most advanced in pioneering the use of climate services based on decadal predictions include water management, agriculture, fishing and wind energy. More details about the issue of skill as one of the aspects of decadal prediction and the scientific gaps that deserve more attention, are discussed by Bojovic (2018).

Recommendation: With regard to activities in WP1, 2, 6 and the multi-user forum (MUF), this situation calls for (i) the evaluation of skill of decadal predictions, especially from a user-perspective in terms of the selection of climate indices as well as the evaluation method and metric, (ii) the development and evaluation of higher-order indicators, i.e. properties that are closer to specific applications. The latter task requires a strong user-involvement because EUCP does not involve much impact modelling. Future meetings between MUF members and EUCP scientists could benefit from identifying specific prototype cases to address these issues.

3.3.6 Timescales

In principle, users expressed interest in predictions on multi-annual to decadal time scales, and they see them as potentially useful (Bender et al., 2012; Dessai and Taylor, 2016). On the other hand, it is not yet clear to them specifically what the benefit of these predictions could be. For example, a user stated to not "understand well the added value of using this kind of decadal climate information and the associated uncertainties." (Soares et al., 2018). For prediction lead times that are within the planning time horizon of most organisations (up to a few years), this concerns the skill originating from the model initialisation in particular. As mentioned above, many studies have found this contribution to be small (Doblas-Reyes et al., 2013). Time scales beyond a few years are outside the operational time horizon of most organisations and mainly affect their strategic long-term planning, associated with vision and strategy for whole organisation.

Recommendation: EUCP can contribute to increasing the user's trust in multi-annual forecasts by improving their quality but also by communicating the skill and uncertainty in user-friendly ways. The sectors most relevant for EUCP would involve important processes on a multiyear time scale, such as forestry, agriculture, energy, water, and transport (Dessai and Soares, 2015), and should be represented in the multi-user forum. Given the unknown and/or limited skill of predictions for variables other than temperature on these time scales, it might be beneficial for EUCP scientists and users to identify promising prototypes (for example, as done in MiKlip or EUPORIAS; see Tiedje, 2015/2016 and Buontempo et al., 2018). Given the interest and novelty in the initialised forcing we recommend WP1 remains actively engaged in discussions concerning setting up EUCP's multi-user forum and making use of it.

3.3.7 Climate variables and indicators

In previous reports, a distinction is typically made between climate variables and climate impact indicators (CII). Indicators are usually more closely related to application-relevant aspects of climate change and variability (Bhend et al., 2016).

However, most end users will not be aware (or interested in) what variables are resolved in climate models, and which are derived in follow-up calculations.

CLIPC distinguishes three tiers of indicators, ranging from physical properties of the climate system (tier 1) to impacts in bio-physical systems (tier 2) and socio-economic impacts (tier 3). Since EUCP involves no impact-modelling, the selection of potential indicators focuses on such properties that are realistic to calculate from climate model output without much further effort.

> **Recommendation:** If a feasible opportunity is identified, EUCP scientists and members of the MUF could develop specific "higher order" indices within or beyond EUCP. The development of indicators should be guided by the user's needs so that they contribute to potential climate services. Therefore, this work should be done within existing activities and working groups, instead of creating an additional working group across WPs.

In principle, users from different sectors are interested in different climate variables (for example, wind energy in wind predictions, solar power in radiation). However, a large overlap exists between the sectors. Moreover, the variables or indicators users are interested in do not differ very much between the time scales involved in their applications (Alexander et al., 2016). This stands in contrast to the skill of predictions, which substantially depends on the time horizon because of technical difficulties such as the initialisation shock, and because different mechanisms are involved on different time scales. The compiled list of climate change indicators presented below therefore ignores the time scales that the individual projects focused on.

Users are interested in a large diversity of variables, often more than are typically available (FMI, 2017b), and with more detailed explanations. Climate indicators are often more interesting for users than direct model variables because they are tailored to certain applications in relevant sectors. This suggests the need of developing different, and more impact-related, indicators. User interest is largest in indicators related to temperature, wind and precipitation (Alexander et al., 2016; Dessai and Soares, 2015). As mentioned above, temperature has typically been shown to have the largest prediction skill on decadal time scales compared to other variables, for example precipitation (Doblas-Reyes et al., 2013). Most important for end users however is the evaluation of changes in the frequency and intensity of extreme weather events, or even worst case scenarios (Alexander et al., 2016; Tiedje, 2015-2017).

The importance of specific variables depends on the sector and application. It is therefore recommended to start from certain phenomena or events when investigating user needs, and only specify the variables in a second step. Many users reported vulnerability to floods, high rainfall, storm surges, landslides, high wind, forest fires, snow, ice, droughts, high temperatures, and lightning (Dessai and Soares, 2015).

Recommendation: The event-based modelling activities in EUCP's WPs 2, 3 and 4 are well-positioned to study the potential for predicting changes in these probability distributions. The list of indicators compiled for this report consequently lists mainly indicators constructed from data with high temporal resolution (hours to days).

The EUCP focus on hydro-meteorological extreme events is well-aligned with user interests and the specific cases and indicators to be evaluated can be discussed in the multi-user forum. It has to be considered though that the prediction skill of precipitation has been found to be low (Doblas-Reyes et al., 2013). Another specific interest of users concerns spatial features such as the size of storms, which points to the need of developing tools that can quantify such indicators automatically from climate data, for example as done within DigitalEarth (https://www.digitalearth-hgf.de/de).

3.3.8 Selection of climate change indicators for EUCP

The objective for this project milestone (MS25) is to "produce a list of most relevant indicators ready for us for further analysis in case studies and end users in WP6." (EUCP Description of Work).

To this end, we produce a list based on previous lists and reports addressing climate change-related indicators, using all sources that were part of or mentioned in the literature informing this report (see Sect. 5), and the indicators listed by the joint CCl/WCRP/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI; https://www.wcrp-climate.org/data-etccdi). The emphasis was hence on sources that had a clear climate-service related context, and that referred to sectors most relevant for predictions on multi-annual time scales. The fact that the reports are based on feedback from users of climate information by conducting surveys and interviews ensures that the list of indicators is, at least to some extent, demand-driven. The list will be further narrowed down to those indicators that are most promising in terms of prediction skill and most relevant to the end users within T4.4 (WP4) during the remainder of the project's duration.

Recommendation: The selection of indicators most relevant to applications will be achieved with the help of the MUF members and end users involved in WP4. As proposed in Cota, Hilden et al. (2015) we hence make the selection of indicators a participatory process to make sure that they fulfill the criterion of being relevant for political decision-makers or practitioners.

We did however not select all indicators listed in the reviewed reports, but based our selection on a few criteria:

- The indicators should be relevant and understandable by potential users, for example we ruled out relatively technical ETCCDI indicators like "count of days with at least 6 consecutive days when TN < 10th percentile", or "Monthly maximum value of daily maximum temperature". Since weather events like cold snaps or heat waves are already represented by other indicators, and since the exact choice of indicators and their construction will be defined later together with users, this selection will not miss important climate phenomena.

- The index is seen as relevant for at least one sector that is affected on EUCP time scales. According to user feedback to previous projects, sectors most interested in multi-annual predictions are agriculture, forestry, tourism, energy and insurance. Users from these sectors were most interested in drought, floods, hail, frost, wind speed, radiation, snow, extreme heat or precipitation, and specific indices designed for agricultural or touristic purposes. All such indicators are hence included in our list.
- Indicators have to be relevant for Europe, i.e. not specific to a region outside Europe.
- It is possible to calculate each index from climate model output, i.e. indicators are usually classified as tier-1 (or in some cases, tier-2) according to CLIPC nomenclature. Since EUCP does not directly involve climate impact research, indicators that are more on the applied side (tier 2 and 3) would need to be defined and calculated in cooperation with users, possibly requiring additional resources.

We decided to not make it a criterion whether observations are available for evaluating a certain indicator, or whether an index is mathematically well-defined because the precise definition to describe the same phenomenon (like heavy rain) can differ. Neither did we assess whether there is enough forecast skill on EUCP time scales for this indicator. This information will be gathered in a related task and workshop (T6.1). In many cases the potential forecast skill will still be a question of ongoing research. Is has been found that temperature and wind (and indicators based on these variables) are the most promising variables in terms of prediction skill. Since both are well represented in our list, it should provide a sufficient basis for identifying potential EUCP products.

Recommendation: We therefore see it as a possible result of the user-engagement to identify which indicators are most relevant to be assessed in their skill by scientists in and beyond EUCP.

Table 1. List of climate-change indicators (MS15).

Realm / basic variable	Index name	Project	Relevant sectors of users
temperature	mean temperature	DECM, EEA, ReKliES-DE, CLIPC	tourism, energy
	heat days per year	ReKliES-DE	tourism
	frost days per year	ReKliES-DE, EUPORIAS, ETCCDI	agriculture, transport, tourism
	icing days per year	ReKliES-DE, EUPORIAS, ETCCDI	agriculture, transport, tourism
	growing degree days	EUPORIAS	
	heating degree days	EUPORIAS, EEA	energy
	cooling degree days	EUPORIAS, EEA	energy
	cumulative degree days		
	cold waves index	EUPORIAS	
	universal thermal climate index	EUPORIAS	health
	thermal stress index	EUPORIAS	health
	ocean temperature	DECM	tourism
	return period of extreme temperature	DECM	energy, transport, water
	frequency of warm days	EEA	
	heat wave magnitude index	EEA	
	longest period of consecutive frost/ice/hot days	ReKliES-DE	energy, tourism
	maximum period of consecutive summer days / hot days	ReKliES-DE	agriculture
	days with alternating frost	ReKliES-DE	agriculture, infrastructure
	calender day with first frost	ReKliES-DE	agriculture
	tropical nights	ReKliES-DE, ETCCDI	tourism
	humid summer days	ReKliES-DE	tourism
	sum of days with cold stress	ReKliES-DE	tourism
	summer days	ETCCDI, ReKliES-DE	infrastructure
	warm-spell duration index (WSDI)	CLIPC	urban vulnerability
other atmosphere-based variables	atmospheric humidity	EUPORIAS, CLIPC	energy, agriculture
	tourism climate index (TCI)	ReKliES-DE	tourism
	Holiday Climate Index (HCI)	ReKliES-DE	tourism

	Climate Index for Tourism (CIT)	ReKliES-DE	tourism
	lightning	ReKliES-DE	energy
precipitation	heavy rainfall index	EUPORIAS	
	standardised precip index	EUPORIAS	
	accumulated precip percentage	EUPORIAS	
	number of days with precip	EUPORIAS	
	number of days with heavy precip	EUPORIAS, Re-KliES-DE	agriculture, hydrology, insurance, energy
	seasonal means	DECM, ReKliES-DE	energy, water
	total precipitation on wet days	EUPORIAS	agriculture, hydrology, insurance
	intense precipitation / heavy precipi-tation / precipitation intensity	EUPORIAS, EEA, ReKliES-DE	hydrology, civil protec-tion, agriculture, tourism
	mean precipitation	DECM, EEA, Re-KliES-DE	tourism, energy
	return period of extreme precipita-tion	DECM	energy, transport, water, coast
	growing season precipitation	Euporias	agriculture
	frequency and duration of hail events	CLIPC	energy
	maximum period of consecutive dry days / wet days	ReKliES-DE	agriculture
	extremely wet days	ReKliES-DE	
wind	storm indices	EUPORIAS	
	wind speed (in specific heights)	DECM, CLIPC	energy
	wind direction (in specific heights)	DECM, CLIPC	energy
	return period of extreme wind	DECM	energy, transport, water
	percentage of time with relevant wind speed	Euporias	energy
	maximum wind speed	EEA	
	days with strong wind / storm	ReKliES-DE	insurance
land / vegeta-tion	Huglin heliothermal index	EUPORIAS	agriculture
	Winkler index	EUPORIAS	agriculture
	Greenness index	EUPORIAS	agriculture
	Selianinov	EUPORIAS	agriculture
	hydrothermal	EUPORIAS	agriculture
	soil moisture	EUPORIAS, Re-KliES-DE, SECTEUR	agriculture, hydrology, insurance
	summer soil moisture	EEA	
	burnt area	EEA	
	forest-fire index	ReKliES-DE	agriculture
	forest fire risk index	EEA	
	fire weather	EUPORIAS	civil protection, forestry

	start and duration of growing season / growing season length	EEA, ETCCDI, ReKliES-DE	agriculture
	day of specific spring events	EEA	agriculture
	average yield	EEA	agriculture
	water deficit (for crops)	EEA	agriculture
	leaf area index, NDVI, FAPAR	SECTEUR	agriculture
drought	water requirement satisfaction index	EUPORIAS	agriculture
	Palmer drought severity index	EUPORIAS	agriculture, hydrology
	return period of droughts	DECM	coast
	frequency and severity of droughts	EEA	
	duration of dry periods	CLIPC, SECTEUR	agriculture, insurance
	SPI (standardized precipitation index)	ReKliES-DE	agriculture
cryosphere	potential hail index	EEA	
	freeze/thaw index		
	snow depth	DECM, ReKliES-DE	energy, transport, tourism
	snow water equivalent	DECM	energy
	duration / extent / amount of snow cover	DECM, EEA, ReKliES-DE	transport, water, energy, agriculture
	sea ice extent	EEA	
ocean	sea level	DECM, EEA, ReKliES-DE	tourism, energy, transport, water, coast
	wave height	DECM	energy, transport, water, coast
	storm surge	DECM	energy, transport, water, coast
	coastal flooding frequency	EEA	
	oxygen content	EEA	fisheries
radiation	sunshine duration	DECM	tourism
	direct net irradiance, total irradiance	DECM, CLIPC	energy
	cloud cover	ReKliES-DE / EUPORIAS	energy
	comfort indices	DECM	tourism
	UV-radiation	ReKliES-DE	health
hydrology (freshwater)	river flow	EUPORIAS, CLIPC	agriculture, hydrology, insurance
	minimum river flow	EEA	
	frequency and magnitude of river floods	EEA	
	lake and river temperature	EEA	

	extreme runoff	CLIPC	agriculture
	surface temperature at shore of lakes, rivers, ocean	CLIPC	tourism
impact-related	temperature-related mortality	EUPORIAS, EEA	health
	costs of extreme events	EEA	
	infected people (vector-born or water/food born diseases)	EEA	health
	risk of landslides	DECM	Energy, transport, water, coast

Table 1 lists all indicators obtained as explained above. The column "project" lists the project reports where users explicitly mentioned the indicator. The column on affected stakeholder sectors is by no means complete, but again indicates which sector users are represented when mentioning a specific indicator in the interviews or surveys. The EEA report does not always provide a clear sector, sometimes only the realm of a variable.

The prediction skill has not yet been evaluated for most of these indicators on decadal time scales. It can be expected that forecasts of indicators are at most as skilful as the time mean of the original variables (for example, the number of heat days compared to the seasonal mean temperature) (Bhend et al., 2016). A lack of skill is usually due to the original variables, not the convolution used to derive the indicator, or the postprocessing (such as bias correction, which is often necessary due to nonlinearities in the definitions of indicators). The challenges are therefore essentially the same as for original model variables, as explained in Sect. 3.3.7. It has to be considered though that skill for hydrological indices (for example river flow) often results from slow variables like soil moisture or snow depth that are typically prescribed in weather prediction models (instead of being predicted interactively).

> **Recommendation:** It should be ensured by the user forum that the models used in EUCP capture the relevant processes involved in a certain climate service product, or that users bring their own expertise to complement these models (e.g. by using impact models).

4 Lessons Learnt and links built

In a nutshell, the following key conclusions emerge from the above analysis:

- Building trust and communicating with users requires time and other resources. It is therefore essential to identify users that are already involved in other common activities (such as conferences), in order to use these as a vehicle to organise EUCP-related meetings.

- The huge scientific progress in multi-annual climate predictions puts EUCP in the promising position to work towards creating new climate services that are directly relevant for users. This opportunity is particularly large for temperature-related information. For other variables and indicators, the uncertainty of prediction skill, or sometimes even the known lack of prediction skill, are a challenge. It is therefore required that the identification and development of such products involves not only the users but also the commitment of scientists from WPs doing the research. The first main task of the MUF should be the "triangulation" of identifying overlap between end user needs, scientific possibilities, and the resources of EUCP. In a fruitful dialogue, scientists can advise users about what indicators can be hoped to have skill, and the muti-user forum might be able to advise EUCP scientists about which climate indicators are most relevant for them to be assessed and evaluated.

- EUCP research has its basis in the development and analysis of climate models, which is far from end-user applications. If specific user-relevant prototypes are to be developed, it may be beneficial to involve different types of users in the multi-user forum in order to bridge all elements of the climate service product chain (for example, by involving impact modelling).

- Users and applications are very diverse and the development of specific products requires time and coordination. Instead of aiming for (only) large meetings with ~30 diverse users of the MUF and EUCP scientists, it is recommended to define smaller teams of users and scientists who focus on their own specific goals within their WP (for example developing a prototype climate service, or at least assessing its feasibility), coordinated by WP6. Even this "small-scale" approach requires regular communication between EUCP scientists across WPs and between the scientists and users within each team, complemented by a detailed and transparent documentation.

Implementation of recommendations: This report will be provided to WPs 6 and 7 in particular to inform them as they form the MUF and further develop communication plans. We also provide our report to the organisers of the General Assembly (GA) to guide the discussion on engagement with users that will form a significant part of the GA in Venice in February 2019. An effective way of using the report is to ensure the facilitators of the discussion sessions are aware of the recommendations. We particularly recommend that WP6 considers the findings of to this report for the planning of future activities with users. Where our report makes reference to particular work packages we will highlight the relevant WP specific recommendation via e-mail to the WP leads before the GA.

On a longer timescale, the findings and recommendations from this report should be considered as basis for the following tasks:

T4.2 (Deltares, BSC, CNRS/IPSL, CMCC, IIASA): Ensemble-based outlook of trends in (cross-)sectoral indicators. Investigation of hydrometeorological extremes and floods, and wind energy predictions. [month 1-48]
This report provides a basis for identifying effective ways of interaction with users and deciding on the goals of the cooperation.

T4.4 (BSC): Validation of developed indicators. [month 13-48]
Within this task, the list of indicators (Table 1) will be narrowed down to the indicators most relevant to EUCP end users.

T6.1 (CMCC & all WP6): Collaboration strategy, including workshops on decadal predictions. [month 1-48]
Our report supports setting the agenda of this workshop by highlighting the gaps between prediction skill and user expectations.

T6.4 (HZG & all WP 6): Engagement with business, policy and decision makers. [month 1-48]

- D6.16, WP6 (UCPH): List of user group membership [month 12]

  (first list of members of the multi-user forum available at https://docs.google.com/spreadsheets/d/1zshgzPnoxCFBfx5lhHq46MUpU0U1m9j6S5PPlG5TSgg/edit#gid=0).
  Our report aims to help refining the criteria for selecting users.

- MS28, WP6 (HZG): First feedback from business and policy stakeholders for the EUCP scientists about applicability of EUCP system. [month 18]
  Our report helps refine the questions asked to the users (e.g. in terms of potential skill of predictions, climate-change indices, resolution, uncertainties).

- D6.11, D6.17, D6.18 (NLeSC): Data access infrastructure for end-users with appropriate documentation [month 42]; Training and workshop about EUCP data service infrastructure. [month 24 / month 36]
  This report provides some guidelines on user expectations on data and the communication of its meaning and uncertainties.

- D6.13, D6.14 (HZG): Concepts for prototype products and business and adaptation strategies; policy briefings ready for dissemination. [month 48]
  This report serves as a basis to find a match between users (practitioners as well as policy-makers) and EUCP scientists that leads to a development of climate services that are both scientifically robust as well as practically useful.

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